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Oil Bypass Filter Technology Evaluation Sixth Quarterly Report January - March 2004

TECHNICAL REPORT

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June 2004

Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

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Sixth Quarterly Report
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ABSTRACT

This Oil Bypass Filter Technology Evaluation quarterly report (January–March 2004) details the ongoing fleet evaluation of an oil bypass filter technology by the Idaho National Engineering and Environmental Laboratory (INEEL) for the U.S. Department of Energy's FreedomCAR & Vehicle Technologies Program. Eight four-cycle diesel-engine buses used to transport INEEL employees on various routes have been equipped with oil bypass filter systems from the puraDYN Corporation. The bypass filters are reported to have engine oil filtering capability of <1 micron and a built-in additive package to facilitate extended oil-drain intervals. This quarter, the heavy-duty buses traveled 88,747 miles, and as of the end of March 2004, the eight buses have accumulated 412,838 total test miles without requiring an oil change. This represents an avoidance of 34 oil changes, which equates to 1,199 quarts (300 gallons) of new oil not consumed and, furthermore, 1,199 quarts of waste oil not generated.

Also this quarter, the light-duty Tahoe test vehicles traveled 62,124 miles, and to date, the six Tahoes have accumulated 81,517 total test miles. This represents an avoidance of 27 oil changes, which equates to 135 quarts (34 gallons) of new oil not consumed and, consequently, 135 quarts of waste oil not generated. However, the quality of the oil in the Tahoes has deteriorated to the point of requiring replacement (Low Total Base Number). The low TBN of the used Tahoe oils is likely due more to the quality of recycled oil initially used in the test than the bypass filters; the recycled oil in the six Tahoes will be replaced with Castrol oil and the testing will restart.

To validate the extended oil-drain intervals, an oil-analysis regime is used to evaluate the fitness of the oil for continued service by monitoring the presence of necessary additives, undesirable contaminants, and engine-wear metals. A more in-depth oil-analysis regimen has been added that focuses on the analysis of particulates, to evaluate the effectiveness of the filters and to ensure that the engines are not experiencing undetected wear due to the extended oil drains intervals.

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Oil Bypass Filter Technology Evaluation
Sixth Quarterly Report

INTRODUCTION AND BACKGROUND

This Oil Bypass Filter Technology Evaluation quarterly report covers the evaluation period January through March 2004.[1] Eight puraDYN PFT-40 (40-quart capacity) oil bypass filter systems (Figure 1) are being tested on Idaho National Engineering and Environmental Laboratory (INEEL) buses. Typically, the buses travel established routes, carrying INEEL workers during their morning and evening trips to and from the INEEL test site (100+ miles per round-trip).

The eight buses are equipped with the following types of four-cycle diesel engines:

- Three buses, Series-50 Detroit Diesel engines
- Four buses, Series-60 Detroit Diesel engines
- One bus, Model 310 Caterpillar engine.

In addition to the eight buses, the filter evaluation includes six light-duty Chevrolet Tahoe test vehicles with eight-cylinder gasoline engines.

This quarterly report covers the following:

- Bus mileage and performance status
- Bus engine oil analysis testing and reporting
- Bus engine oil particulate count analysis
- Light-duty vehicle mileage and performance status
- Light-duty vehicle filter evaluation: lessons learned.

A list of all prior quarterly reports and the major topics is presented in Table 1.

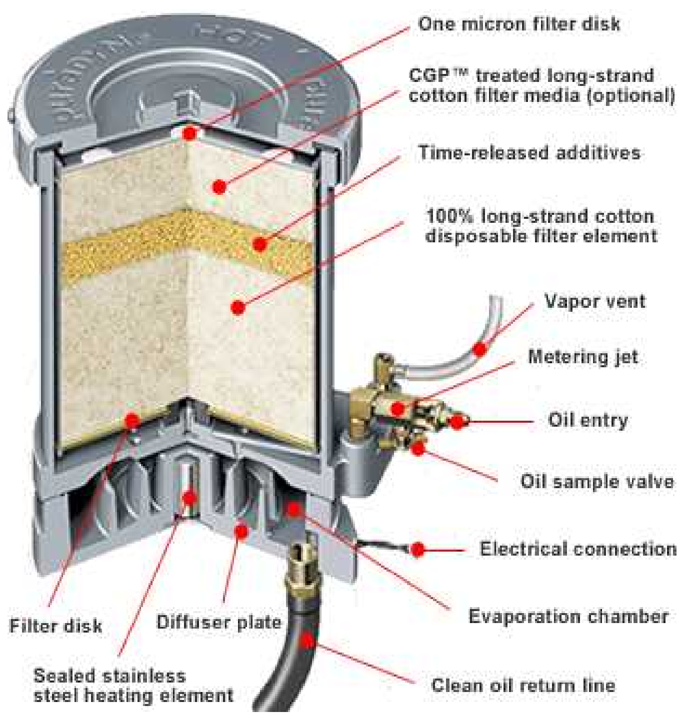

Figure 1. Cutaway of a puraDYN oil bypass filter

HEAVY VEHICLE TESTING ACTIVITIES

Bus Mileage and Performance Status

During this reporting quarter (January—March 2004), the eight diesel-powered buses traveled approximately 88,747 miles, an increase over the last quarter by 14,337 miles. Figure 2 shows the quarterly and cumulative evaluation miles. Table 2 details the mileage status of the eight test buses. Figure 3 shows the total evaluation miles per bus, by evaluation quarter.

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[1] The U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program funds this activity.

Table 1. Reporting dates, report numbers, and major topics covered for the previous Quarterly reports. All of the reports are available online at http://avt.inel.gov/obp.html.

Reporting Quarter	Report Number	Major Topics
10/02 – 12/02	INEEL/EXT-03-00129	• Background on fleet operations, vehicles, filters, and oil selection • Performance evaluation status • Economic analysis • Photographs of installed systems • Bypass Filtration System Evaluation Test Plan
1/03 – 3/03	INEEL/EXT-03-00620	• Background on reports • Bus mileage and performance status • Revised filter replacement schedule • Oil-analysis sampling • Light-duty vehicle test status
4/03 – 6/03	INEEL/EXT-03-00974	• Background on reports • Bus mileage and performance status • Preliminary trends in oil analysis reports • Revised economic analysis • Ancillary data • Light-duty vehicle test status
7/03 – 9/03	INEEL/EXT-03-01314	• Background on prior quarterly reports • Bus mileage and performance status • Used engine-oil disposal costs • Unscheduled oil change • Light-duty vehicle test status
10/03 – 12/03	INEEL/EXT-04-01618	• Bus mileage and performance status • Bus oil analysis testing and reporting • Light-duty vehicle filter installations • Light-duty vehicle filter installations lessons learned • Light-duty vehicle filter evaluation status

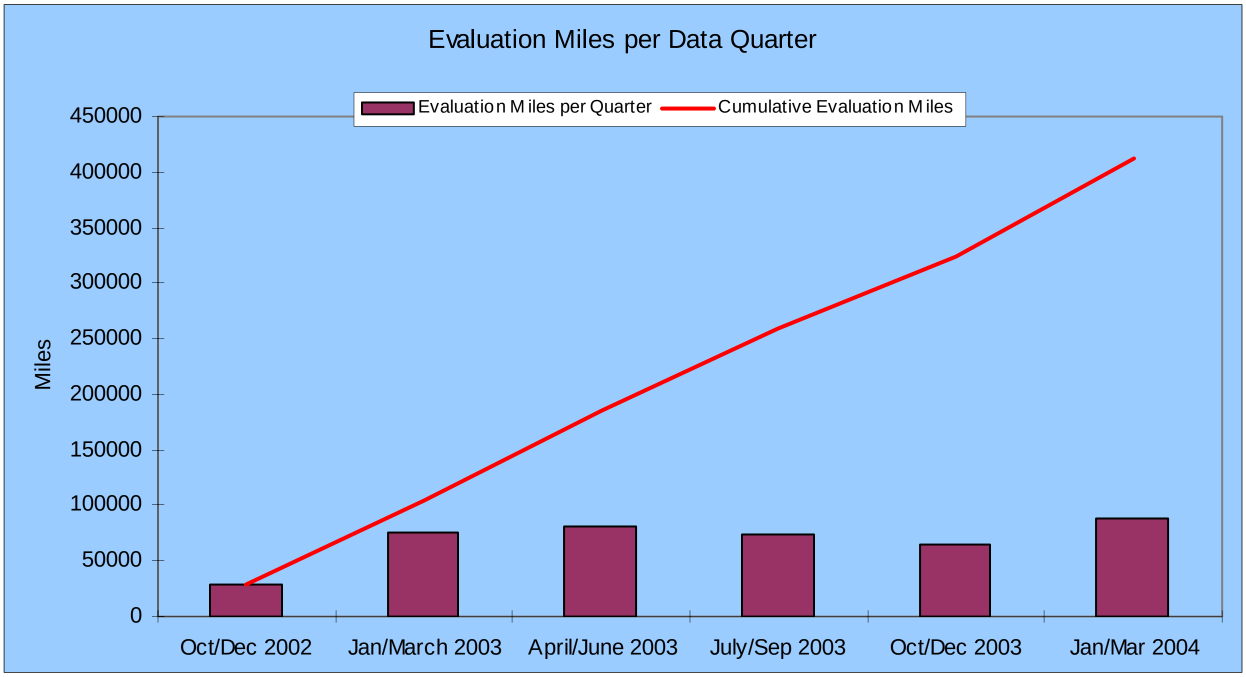


Figure 2. Quarterly and cumulative evaluation miles per evaluation quarter.

Table 2. Test buses and test mileage on the bus engine oil as of March 31, 2004.

Bus Number	Test Start Date	Bus Mileage at Start Date	Current Bus Mileage (3/31/04)	Total Oil Evaluation Test Miles
73425	12/18/2002	41,969	77,364	35,395
73432	2/11/2003	47,612	97,367	49,755
73433	12/4/2002	198,582	252,218	53,547
73446	10/23/2002	117,668	165,340	47,672
73447	11/14/2002	98,069	142,278	44,209
73448	11/14/2002	150,600	192,112	41,508[1]
73449	11/13/2002	110,572	150,215	39,643
73450	11/20/2002	113,502	214,611	101,109
			Total (3/31/04)	412,838

[1] The oil on bus 73448 was inadvertently changed on 9/16/03. This total includes both oil tests on bus 73448.

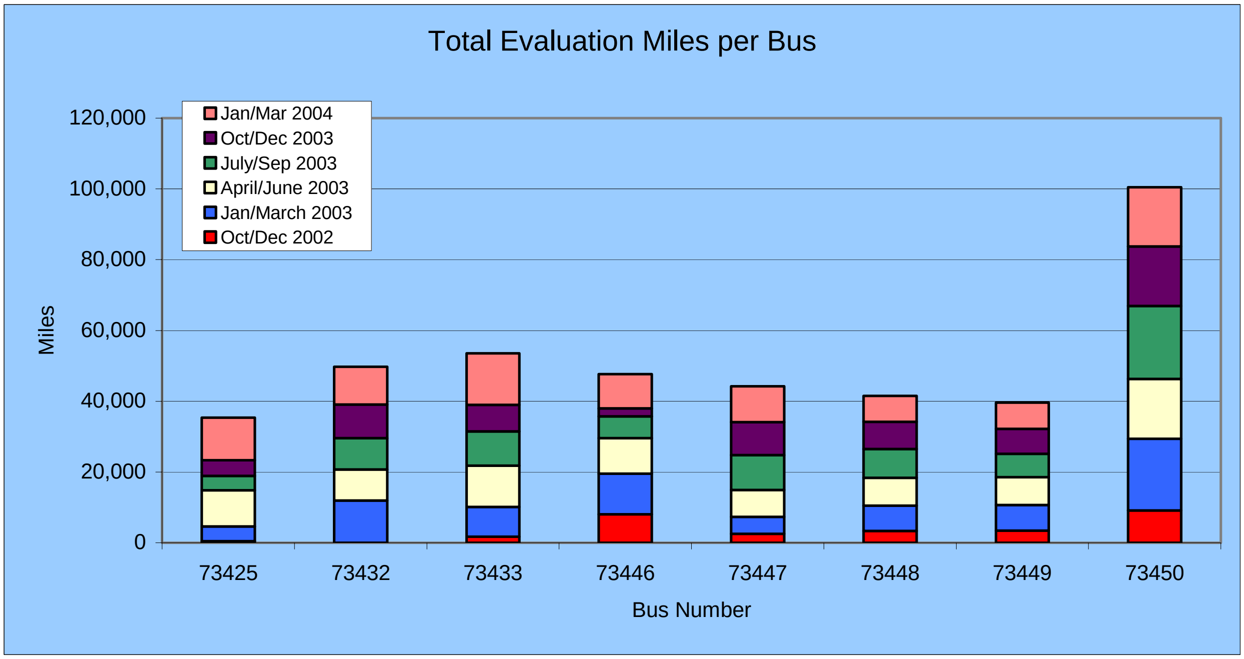


Figure 3. Total evaluation miles per bus by testing quarter.

Bus Engine-Oil Analysis Testing and Reporting

As of the end of March 2004, 108 used-oil analysis reports for the eight buses had been obtained; with 20 new oil analysis reports generated this quarter. All oil analysis reports are generated during a vehicle-servicing event, when the bypass filter and/or full-flow filters are exchanged and an oil analysis sample taken. The research plan calls for all samples to be sent to two different laboratories for comparative purposes. This quarter, a new oil analysis laboratory was employed to provide specific data germane to particulate analysis of used oil. The used-oil analysis reports provide the empirical data for this research, and the new-oil analysis reports provide baseline data on the oils used in the test.

Oil Quality / Physical Properties

One section of the oil analysis report focuses on the oil quality (also known as the physical properties of the oil), which is determined by measuring the presence of fuel, water and glycol, and determining oxidation and nitration numbers, total base number (TBN), soot content, and viscosity. (A detailed discussion on these topics is found in the appendix of the First Quarterly Report). These oil quality variables are the metrics for definitively evaluating the oil quality in the eight test buses. There are specific values each variable should remain above or below in order for the oil to be considered acceptable or fit for continued use.

The fuel, water, and glycol contaminate values for the bus engine oils have never been above the minimum reporting values and remained unchanged (and acceptable) throughout the testing period. The oxidation and nitration data are shown in Table 3. When the Shell Rotello engine oil used in the oil bypass filter evaluation is new, the oxidation and nitration values are both 0.1 absolute per cubic centimeter (Abs/cm); one of the testing laboratories suggested that the upper limit (oil condemnation limit) be 30 Abs/cm.

Oxidation and nitration values are determined by a spectrometric technique. These values reflect the organic contaminants and oil degradation level or products in used oil. The TBN values for the bus engine oils in this quarter (Figure 4) are mixed, with up and downward trends, though still acceptable.

Soot levels in the bus engine oils (Figure 5) generally show a slightly improving trend toward lower levels. The viscosity levels (Figure 6) remain fairly constant and acceptable

When viewing Figures 4 through 6, the bottom scale (x axis) indicates the number of oil analysis reports (1 through 10) graphed for each bus. Generally, the first and second test results for each bus were conducted at 6,000 and 12,000 miles of oil use, with each additional test scheduled at 12,000-mile intervals.

Table 3. Oil analysis report histories for oxidation and nitration.[1]

Bus No.	Test Date	Oxidation[2]	Nitration[2]	Notes
New oil	3 dates	0.1	0.1	Same for 3 tests
73425	11/11/03	8	3	ANA Laboratory
	12/10/03	7	3	ANA Laboratory
	1/2/04	9	4	ANA Laboratory
	2/2/04	11	6	ANA Laboratory
73432	11/4/03	9	1.5	ANA Laboratory
	12/17/03	9	1.7	ANA Laboratory
73433	12/18/03	10.1	2.2	ANA Laboratory
	3/4/04	2	0	CTC Laboratory
73446	11/10/03	10	6	ANA Laboratory
	12/16/03	7	2.9	ANA Laboratory
73447	11/15/03	9	2.5	ANA Laboratory
	2/4/04	11.2	4.1	ANA Laboratory
73448	11/4/03	11	3.2	ANA Laboratory
	1/2/04	10	4	ANA Laboratory
73449	11/4/03	9	3.2	ANA Laboratory
	2/8/04	8.5	3	ANA Laboratory
	2/18/04	12	5	CTC Laboratory
73450	10/6/03	11	3	ANA Laboratory
	10/28/03	11.3	3.4	ANA Laboratory
	1/13/04	13	5	ANA Laboratory
	3/4/04	21	6	CTC Laboratory

1: Oxidation and nitration data compiled from reports from two oil analysis laboratories.

2: Abs/cm = absolute per cubic centimeter.

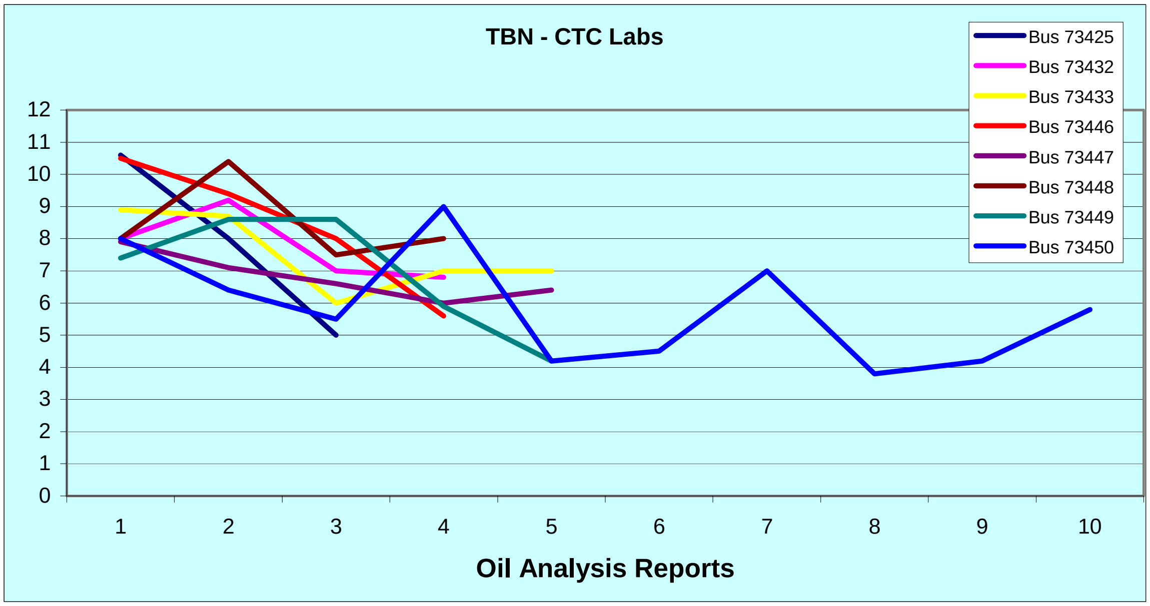


Figure 4. Total base number (TBN) is a measure of the presence of additives that neutralize an acid buildup. A TBN of 3.0 (mgKOH/mL) or below is considered low, and the oil should be changed.

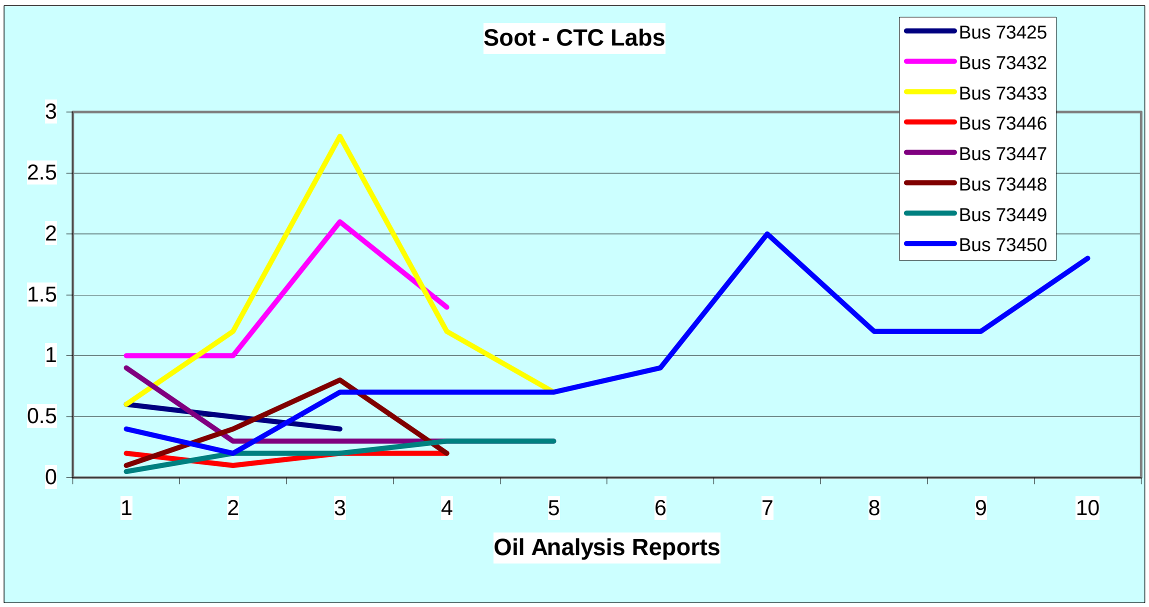


Figure 5. Soot testing measures the presence of solids in the oil from the combustion process. Excessive solids may possibly impair anti-wear benefits and, indirectly, perhaps lead to additional wear above normal for a given engine. Soot levels exceeding 3% indicate the oil should be changed.

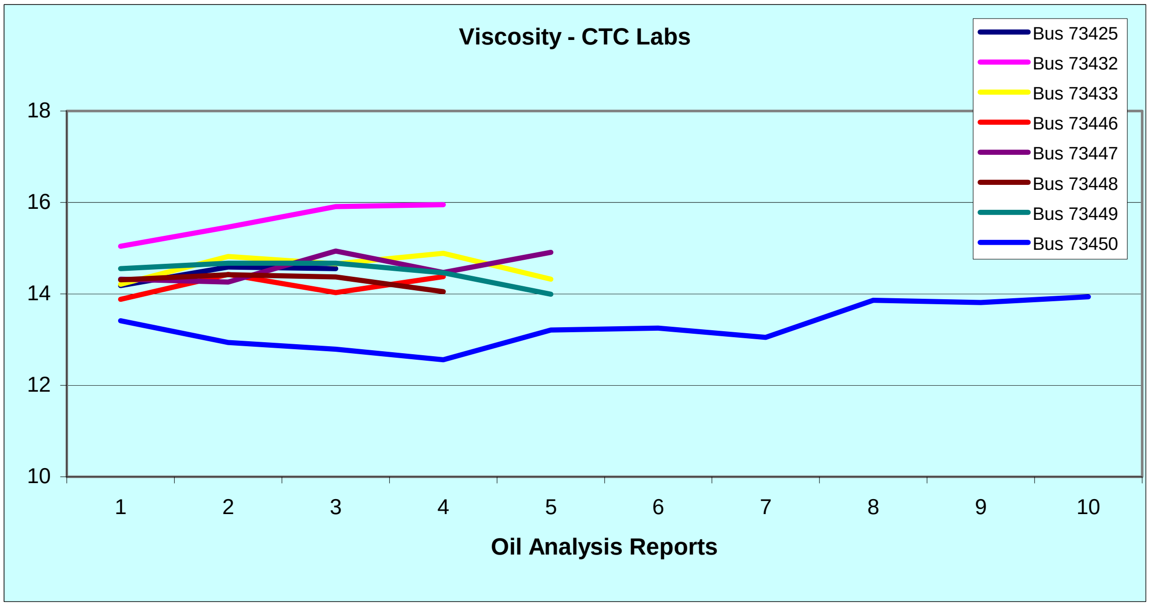


Figure 6. Viscosity is the oil's resistance to flow with respect to temperature, as measured in centistokes (cst). The limits for viscosity are based on the SAE grade specified; SAE 40 has a range of 12.50 to 16.29 cst. The test oil used in the bus engines is 15W–40; all bus oil is within acceptable range.

Spectrochemical / Elemental Analysis

Spectrochemical analysis is used to detect and quantify the parts per million (ppm) of engine wear metals and additives in oil. As metal engine parts wear, the particles contaminate the oil, and engine parts have a material (metal) signature. When the wear metals are quantified, they give a qualitative evaluation of the condition of the engine. If a certain wear metal exceeds established limits, it acts as a warning that a part or subsystem is failing. Wear metals do not necessarily condemn an oil for extended oil use, and just changing the oil will not heal the part or subsystem that is failing. This analysis also qualitatively measures the additives (anti-foaming agents, detergents, etc.) in the oil, and if the additives were to deplete, the oil-quality measures would show the effects of this degradation. There were no negative additive value changes evident in the oil analysis reports for this quarter.

Iron is the dominant engine wear metal present in this and in previous reporting quarters. Typically, an oil analysis sample is taken and the iron values are determined from the oil discarded at a scheduled servicing. As discussed in greater detail in previous quarterly reports, a paradox exists with extended oil-drain intervals, as the oil is not drained but only tested. With extended intervals, a negative trend of iron values can be somewhat misleading when viewed conventionally. With extended oil-drain intervals, metals can continue to accumulate at a normal pace, while the conventional analysis results suggest high levels of accumulated engine wear-metal contaminants, which are actually acceptable when a wear-rate ratio is considered.

The wear-rate ratio is determined by dividing the total ppm of metal in the oil by each 1,000 miles traveled. If the wear-rate remains relatively constant over time, higher wear-metal content is not considered to be harmful. However, if wear-rates were to radically increase (double or triple) over consecutive oil tests, then repair action should be taken; i.e., overhauling the engine to remove the failing part before catastrophic failure occurs. Table 4 shows the iron wear-rate ratios for all of the buses.

Table 4. Oil analysis report histories for iron wear metal.[1]

Bus Number	Test Date	Miles on Oil	Iron (ppm) [2]	Iron Wear-Rate Ratio[3]
73425	4/2/03	6,376	15	2.4
	6/3/03	12,919	33	2.6
	2/2/04	28,408	128	4.5
73432	3/11/03	6,0921	24	3.9
	4/14/03	12,320	28	2.3
	8/11/03	24,935	60	2.4
	12/17/03	38,868	76	2.0
73433	2/12/03	6,700	30	4.5
	5/4/03	13,322	49	3.7
	7/29/03	25,617	124	4.8
	12/18/03	38,487	130	3.4
	3/3/04	46,140	112	2.4
73446	1/15/03	9,949	11	1.1
	1/30/03	12,136	8	0.7
	4/30/03	22,648	18	0.8
	12/16/03	37,827	44	1.2
73447	3/11/03	5,908	9	1.5
	6/18/03	13,780	15	1.1
	7/21/03	17,164	15	0.9
	10/13/03	26,089	38	1.5
	2/4/04	41,833	45	1.1
73448	1/20/04	11,207	12	1.1
73449	2/4/03	6,168	5	0.8
	4/22/03	12,572	10	0.8
	9/11/03	24,771	15	0.6
	1/20/04	36,941	38	1.0
73450	1/8/03	6,934	20	2.9
	1/21/03	14,545	50	3.4
	3/17/03	25,871	91	3.5
	6/16/03	43,031	206	4.8
	7/2/03	45,968	162	3.5
	7/23/03	54,812	183	3.3
	8/25/03	65,369	212	3.2
	10/6/03	68,821	425	6.2
	1/13/04	87560	305	3.5
	3/4/04	99703	370	3.7

1: Oil analysis reports from CTC laboratory of Phoenix, Arizona.
2: ppm = parts per million.
3: Wear-rate ratio (ppm/k miles).

Bus Engine Oil Particulate Count Analysis

Particulate count analysis began in this reporting quarter, and it is anticipated that it will continue throughout the bypass filter evaluation. Characterizing the particulates in the oil is critical in determining the effectiveness of a filter. During this reporting quarter, six of the eight test buses were serviced and oil samples were taken and sent to National Tribology Services, Inc. (NTS) of Minden, Nevada for analysis. The NTS laboratory uses a DOUBLECHECK Oil Monitoring Program (Appendix A) for analyzing both oil and particulate count. The four techniques or methods are used for characterizing particulates (discussed it detail below):

- Spectrometric analysis
- Rotrode filter spectroscopy
- Particle count
- Analytical ferrography.

Typically, oil analysis measures three conditions:

- Lubricating quality of the oil (viscosity/TBN)
- Engine wear metals (iron/copper)
- Oil contaminates (fuel/water).

The four techniques either directly or indirectly measure the condition of the oil, but the primary focus of this particulate-count analysis exercise is to characterize and determine the size the particulates in the oil. When additional data become available, comparisons will attempt to be made between engines with and without bypass filter systems.

The testing of the bus oil by NTS and the use of the four characterizing techniques was started not only to generate a second data set of oil conditions, but also to measure the total range of particles sizes, with the particulates measured in microns (μm). For readers unfamiliar with how large a micron is, the periods created by the 11-point Times New Roman font used in this report are about 500 microns in diameter. A micron (or micrometer) is one millionth of a meter, or 0.000039 inches. The human eye can discern an object of about 10 microns. The distance between the main bearings and the crankshaft of an engine can be 0.001 inch, or 25 microns. Lubrication industry literature suggests that when contaminates in the 5- to 20-micron range are removed or captured by the oil filter, 60% of engine wear can be eliminated. Standard full-flow engine-oil filters for internal combustion engines filter particles down to the 40- to 60-micron range. Therefore, particulate-count analysis is essential to evaluate the effectiveness of bypass filtration and ensure that the engines are not experiencing undetected wear due to extended oil-drain intervals.

Spectrometric Analysis

Spectrometric analysis is the main method of quantifying metallic elements in used oil. This analysis identifies the contaminate metal and quantifies the amount (volume in ppm) of the contaminate metal. It does not directly measure the size of the individual metal contaminates, as spectrometric analysis apparatus typically can process only particles that are less than 4 microns in size.

During this quarter, bus 73450 had two service events and, consequently, two particle analysis tests were conducted (Table 5).

Table 5. Spectrometric analysis results.

Wear Metals (particles <4 µm)		
	1/13/04 (ppm)	3/4/04 (ppm)
Iron	240	211
Chromium	4	3
Lead	14	11
Copper	18	16
Tin	2	2
Aluminum	3	2
Nickel	1	0
Silver	0	0
Molybdenum	4	3
Titanium	0	1
Additives and Contaminants (particles <4 µm)		
Silicon	5	5
Boron	1	0
Sodium	8	5
Magnesium	28	23
Calcium	3,398	3,170
Barium	0	0
Phosphorous	1,009	977
Zinc	1,138	988

Rotrode Filter Spectroscopy

Rotrode filter spectroscopy is another method of characterizing particulates in oil. This method processes particulates in the 4-, to as high as 20-micron, size. These larger particles can be the first indicators of abnormal wear conditions (they are too large for detection using spectrometric analysis). This process forces oil through a porous disk or filter to capture the larger particulates. The particulates are washed with a solvent and the remaining particulate metals (iron, copper, etc.) are identified with a rotating disc electrode spectrometer.

During this quarter, bus 73450 had two service events and, consequently, two particle analysis tests were conducted (Table 6). Oil-analysis engineers at NTS suggest that a 50-ppm result be an upper limit trigger point to a serious wear-metal condition.

Particle Count

Particle-count analysis does not identify metals; it bins the particulates into size ranges or scale numbers per 100 ml volume of oil. Table 7 shows the particle count performed by NTS on two oil analysis samples from bus 73450. Additional tests may even out the wide ranges between the two data sets.

Table 6, Rotrode filter spectrometric analysis results for bus 73450 (particle sizes 4 to 10 μm).

Wear Metals	1/13/2004 (ppm)	3/4/2004 (ppm)
Iron	23	14
Chromium	1	0
Lead	0	0
Copper	1	1
Tin	0	0
Aluminum	1	0
Nickel	0	0
Silver	0	0
Moly.	0	0
Titanium	0	0
Contaminants		
Silicon	1	0
Boron	0	0
Sodium	0	0

The NTS results also include a secondary breakdown of the particle binning to ISO 4406 (international standards organization), a cleanliness code. Table 8 shows the ISO binning results for the same two bus 73450 tests. ISO 4406 has a three-part cleanliness code based on the number and range of particles in 1 ml volume of oil. The code is represented as $R_4/R_6/R_{14}$. R_4 represents the number of particles greater than or equal to 4 μm in size; R_6 represents the number of particles greater than or equal to 6 μm in size; and R_{14} represents the number of particles greater than or equal to 14 μm in size. The ISO code allows the end user to scale or rank the used oil to a standard, and NTS has defined 19/17/14 as an acceptable target of cleanliness. The January 1, 2004 test result had an ISO code of 20/19/16, and the March 4, 2004 test was 17/16/13. The second sample is much cleaner and is under the acceptable clean target values.

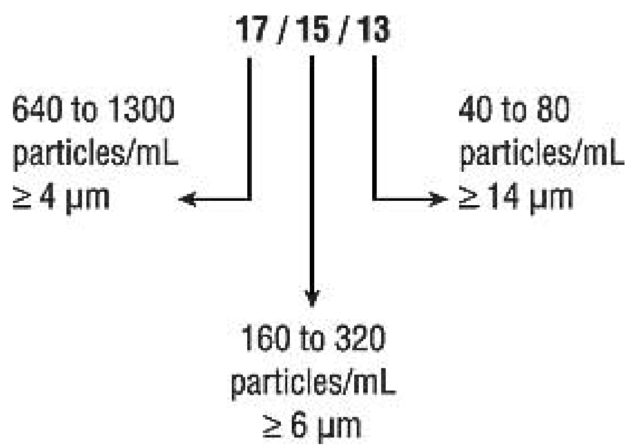
Table 7. Binning of particle count results.

ISO 1121/4406	Particle Count Result, Particles >4 to >70 um	
Size in um	1/13/2004	3/4/2004
>4	683,300	83,300
>6	372,200	45,300
>14	63,400	7,700
>21	21,400	2,600
>38	3,300	400
>70	300	0

Table 8, ISO 4406 (international standards organization) fluid cleanliness codes.[1]

Number of Particles Per 1 milliliter of Fluid		
ISO Code	Minimum	Maximum
1	0.01	0.02
2	0.02	0.04
3	0.04	0.08
4	0.08	0.16
5	0.16	0.32
6	0.32	0.64
7	0.64	1.3
8	1.3	2.5
9	2.5	5.0
10	5.0	10.0
11	10.0	20.0
12	20.0	40.0
13	40.0	80.0
14	80.0	160.0
15	160	320
16	320	640
17	640	1300
18	1300	2500
19	2500	5000
20	5000	10000
21	10000	20000
22	20000	40000
23	40000	80000
24	80000	160000
25	160000	320000
26	320000	640000
27	640000	1300000
28	1300000	2500000

ISO Code Example



[1]http://www.bently.com/articles/4Q01orbit/4Q01whitefield.asp.

Analytical Ferrography

Analytical Ferrography is another effective method to characterize wear modes and contaminates in used oil. Wear modes define the mechanism of generating metal shards or pieces. A partial list of wear modes includes rubbing wear, cutting wear, and sliding wear. Ferrography is used to characterize not only ferrous-based material but also nonferrous and other contaminates. The term *ferrogram* refers to the process where oil is thinned with a solvent, poured onto a glass slide, and placed over a permanent magnet. The ferrous materials line up with the magnetic lines of flux. The nonferrous materials will randomly fall in between the ferrous particles on the glass slide. Through microscopic examination, the particle size, composition, wear modes, sources of wear, and contaminates can be determined. The NTS analytical ferrography testing results include:

- Wear particle modes or types
- Interpretive comments
- Photograph of the particulates on the glass slide.

Table 9 shows the January 13, 2004 and March 4, 2004 NTS analytical ferrography testing reports for bus 73450, while Figure 7 is a photograph of the particles found during the January 13, 2004 testing. The NTS testing laboratory results included the following comment: *This ferrogram test shows a trace amount of fine (<10 μm) ferrous particulate, typical of normal rubbing wear. A discrete laminar nonferrous wear particle, measuring 88 by 28 μm is noted, but not considered problematic at this time.*

Figure 8 is a photograph of the particles found during the March 4, 2004 testing; the NTS testing laboratory results included the following comment: *The Ferrogram test shows a trace amount of fine (<10 μm) ferrous particulate, typical of normal rubbing wear, but is not considered problematic at this time.*

Table 9. Wear particle types or modes.

Wear Particle Types	1/13/04	3/4/04
Rubbing wear	1[1]	1
Severe wear	0	0
Cutting wear	0	0
Fatigue particles	0	0
Laminar particles	1	1
Spheres	0	0
Dark metallic oxide	0	0
Red oxide corrosive	0	0
Nonferrous metals	1	0
Nonmetallic inorganic	0	0
Organic	1	0
Nonmetallic amorphous	0	0
Friction polymers	0	0
Fibers	0	0

[1]Population ratings: 0 = none
2 =trace
3 = moderate
9 = heavy

Figure 7. Picture (250x) of the ferrogram test for the sample taken January 13, 2004 from bus 73450.

Figure 8. Picture (250x) of the ferrogram test for the sample taken March 4, 2004 from bus 73450.

LIGHT-DUTY VEHICLE TESTING ACTIVITIES

Light-Duty Vehicle Mileage and Performance Status

During the previous reporting quarter, six 2002 Chevrolet Tahoe sport utility vehicles were selected for testing and outfitted with puraDYN PFT-8 filter systems (8-quart capacity). Table 10 lists the date of and mileage at installation, and the test miles and oil changes avoided.

Table 10. Light-duty vehicle installation and mileage information for the six INEEL Tahoes with the oil bypass test systems installed.

Vehicle	Date Filter Installed	Vehicle Mileage at Installation	Vehicle Mileage (3/31/04)	Oil Filter Evaluation Miles	Actual Oil Changes Avoided[1]
71326	12/10/03	45,812	60,845	15,033	3
71333	11/12/2003	40,825	55,734	14,909	2
71391	12/17/2003	34,910	46,863	11,953	4
71394	12/4/03	43,938	57,052	13,114	3
71400	11/24/2003	43,966	58,595	14,629	3
71402	12/4/2003	38,618	50,273	11,655	3
			Total Miles	81,293	18 Service Events

[1]Service is scheduled at 3,000 miles, but often the interval is greater because of vehicle usage.

The Tahoes have had 18 service events since the oil bypass filter systems were installed. With each service event, the filter(s) are serviced, an oil analysis sample is taken, and a testing report is ultimately generated. Between the three oil test laboratories used, there have been 25 used oil samples taken and 25 reports received. From the oil analysis reports, two items are evident:

- The copper levels have dropped
- The TBN values are also dropping.

The copper levels (copper is an engine wear-metal) have dropped significantly since the bypass filters were installed in the Tahoes. It appears that the filter systems are filtering the copper. Before the bypass filter systems were installed onto the Chevrolet Tahoe engines, the used oil was sampled several times on each engine to establish a baseline of the engine wear-metal patterns. Five of the six test Tahoes consistently had high copper readings (between 58 and 242 ppm) before bypass filter installation. After the bypass filters were installed, the five vehicles had consistent copper readings between 16 and 39 ppm, an average reduction in copper contaminate in the oil of 63%. This reduction is likely an indirect measure of the capability of bypass filtration in filtering particles sized less than 4μm.

The TBN values (Table 11) show a dramatic degradation from the TBN (5.8) of the new oil. The Americas Choice 10W-30 oil being used in the Tahoes is manufactured with 25% recycled oil, and when compared to commercially available virgin oils, it has a lower TBN when new. The TBN values for the used oil in the Tahoes (Table 11) are at or near the lower limit for condemnation (3.0). Therefore, when these light-duty vehicles come in for their next service, the oil will be changed. The replacement oil will be Castrol 10W-30, and the Tahoes’ tests will restart.

Table 11. TBN[1] Values for Tahoes

Vehicle	Service Date	Total Base Number
71326	1/2/04	3.5
	2/16/04	3.8
	3/10/04	2.8
71333	12/23/03	5.3
	1/12/04	2.6
	2/23/04	2.8
71391	12/31/03	8.2
	1/26/04	3.8
	3/9/04	2.12
	3/29/04	1.98
71394	1/21/04	3.2
	2/25/04	2.6
71400	1/8/04	2.4
	1/22/04	2.6
	2/24/04	2.4
71402	1/13/04	3.2
	2/12/04	3.2
	3/17/04	2.6

[1]Total base number for new 10W-30 Americas Choice oil is 5.8

Light-duty Vehicle Filter Evaluation: Lessons Learned

The Oil Sampling Valve

In the supply line feeding oil to the bypass filter from the engine, there is an oil-sampling valve. The valve allows the mechanic to take an oil analysis sample when the bypass filter is serviced. With the engine running, the mechanic places the sample bottle under the oil sampling valve and then opens the valve to allow the oil to fill the bottle, which is then sent for analysis. On March 1, 2004, after vehicle 71400 was warmed up (Idaho is still cold at that time of the year), the operator noticed oil dripping from the engine. At the shop, the mechanic discovered that the oil-sampling valve was not tight, and most of the oil had leaked out.

SUMMARY

Eight puraDYN PFT-40 (40-quart capacity) oil bypass filter systems are being tested on eight INEEL buses. To date, the eight buses have accumulated 412,838 miles. With a 12,000-mile servicing schedule, this represents an avoidance of 34 oil changes, which equates to 1199 quarts (300 gallons) of new oil conserved and 1199 quarts of waste-oil not generated.

Oxidation and nitration analysis have been added to the suite of oil analysis tests to measure fitness of the oil, and data are being collected. For the bus engines, the oxidation and nitration levels are rising but are well below the condemnation limit.

Six puraDYN PFT-8 (8-quart capacity) oil bypass filter systems are being tested on six Chevrolet Tahoe vehicles. To date, the six vehicles have accumulated 81,517 miles. With a 3,000-mile service schedule, this represents an avoidance of 27 oil changes, which equates to 135 quarts (34 gallons) of new oil conserved and 135 quarts of waste-oil not generated.

Oil quality values were graphed of TBN, soot, and viscosity from all of the CTC Laboratory oil analysis reports received to date. The graphs show that oil quality is degrading for TBN, but all of the bus engine oils are still within safe operating limits. The graphs for soot are mixed, with four buses remaining constant, three buses decreasing, and one increasing. The graphs for viscosity are relatively flat or consistent and show no negative trends.

For the bus engines, the wear-rate ratios (ppm of metal/1,000 miles) were calculated for iron; this wear metal is remaining relatively constant and is showing no negative changes. The other metals are not showing any significant rates of change.

Particulate-count analysis began in this quarter. A more complete comparison between filtered-test vehicles and nonfiltered test vehicles will be conducted next quarter, but the ferrogram results of two samples from bus 73450, with 107,000 miles on the oil, show only a trace-amount of particles. This indicates that this engine is not experiencing undetected wear due to extended oil drain intervals.

One of the established oil quality metrics for this evaluation is TBN. The TBN of the Tahoe test vehicles has deteriorated to the condemnation level (<3.0 mgKOH/g) during this quarter. The Americas Choice oil originally used, containing 25% recycled oil, has a TBN number of about 6 (mgKOH/g) when new. The Tahoe testing is being restarted using Castrol 10W-30 oil, which has a significantly higher TBN value.

Appendix A - NTS DOUBLECECK Oil Monitoring Program

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DOUBLECHECK Oil Monitoring Program

Important Tests in Oil Analysis

Why Wear Analysis: Relative motion between lubricated parts is always accompanied by friction between the contacting surfaces. This friction causes a gradual wearing away of these surfaces, despite the fact that the parts themselves are usually coated with a thin film of oil. Metal particles rubbed off in this manner are small enough to remain suspended in a circulating lubrication system, and since these wear products are always composed of the same materials from which they originated, the relative level of each metal present in the used oil relates directly to the wear condition of the lubricated assemblies.

Spectrometric Analysis: Technique for detecting and quantifying metallic elements in a used oil resulting from wear, contamination or additives. The oil sample is energized to make each element emit or absorb a quantifiable amount of energy, which indicates the element's concentration in the oil. These values are classified as "fine" readings on your report, and reflect the concentration of all dissolved metals (from additive packages) and particulates up to 2 microns in size.

Doublecheck Analysis: The resistance of a fluid to flow. Viscosity is the most important lubricant physical property. Lubricants must have suitable flow characteristics to ensure that an adequate supply reaches lubricated parts at different operating temperatures. The viscosities of lubricants vary depending on their classification or grade, as well as the degree of oxidation and contamination in service. If viscosity of the lubricant differs by more than 10% from nominal grade, a change of oil is recommended.

Total Acid Number: A titration method designed to indicate the relative acidity in a lubricant. The acid number is used as a guide to follow the oxidative degeneration of an oil in-service. Oil changes are often indicated when the TAN value reaches a predetermined level for a given lubricant and application. An abrupt rise in TAN would be indicative of abnormal operating conditions (e.g., overheating) that require investigation.

Total Base Number: The converse of the TAN, this titration is used to determine the reserve alkalinity of a lubricant. The TBN is generally accepted as an indicator of the ability of the oil to neutralize harmful acidic byproducts of engine combustion.

Infrared Analysis (FT-IR): Spectrometric technique for detecting organic contaminants and water and oil degradation products in a used oil sample. During a lubricant's service life, oxidation products accumulate, causing the oil to become degraded, and in most instances, slightly acidic. If oxidation becomes severe, the lubricant will corrode the equipment's critical surfaces. The greater the oxidation number, the more oxidation is present. Similarly, the nitration number reflects the level of nitrogen compounds in the oil resulting from nitrogen fixation (common in natural gas fueled engines). Conditions such as varnishing, sludge deposits, sticky rings, lacquering, and filter plugging, occur in systems with oxidation and/or nitration problems. Infrared spectroscopy also indicates contamination due to free water, glycol antifreeze, soot deposits and fuel dilution.

Water: Usually not desirable in oil, water can be detected visually if gross contamination is present (cloudy appearance). Water contamination should not exceed 0.25% for most equipment, and not more than 100 ppm for turbine lube and control systems. The Karl Fischer method is used for moisture contamination down to levels of 10 ppm (.001). Excessive water in a system destroys a lubricant's ability to separate opposing moving parts, allowing severe wear to occur with resulting high frictional heat.

Particle Count: A method used to count and classify particulates in a fluid according to accepted size ranges, usually to ISO 4406. High counts lead to filter plugging, servo valve jamming, and hydraulic piston failure. The test is a good reflector of filter efficiency. Turbine systems typically should not exceed ISO 18/16/12, although some applications require more stringent limits.

Ferrography: A technique which separates magnetic wear particles from the oil and deposits them on a glass slide known as a ferrogram. Microscopic examination permits characterization of the wear mode and probable sources of wear in the machine.

Benefits of Oil Analysis:

- Reduce in-service equipment failures
- Easier scheduling of repairs
- Identifies maintenance problems
- Maintains high equipment productivity
- Decreases repair costs.